National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 25, 1998
In reply refer to: A-98-25 and -26

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On January 26, 1997, Northwest Airlines (NWA) flight 20, a Boeing 747-251, N627US, experienced an engine case rupture of its No. 1 Pratt & Whitney (P&W) JT9D-7Q engine during takeoff at Narita International Airport, Tokyo, Japan. During the takeoff roll, as engine power was set to approximately 1.58 engine pressure ratio and the airplane was rolling forward at low speed, a loud bang was heard by the flightcrew. The captain rejected the takeoff and returned to the gate without further incident; no injuries resulted. The crew reported that there were no fire warning or nacelle overheat indications. The airplane was operated under Title 14 Code of Federal Regulations Part 121, as a regularly scheduled passenger flight from Tokyo, Japan, to Minneapolis, Minnesota.

The No. 1 engine diffuser case ruptured and as a result, both engine side cowl doors, a precooler, and other hardware were ejected from the engine. The escaping gas and engine debris blew out the engine pylon access panels, and created holes, cracks, and other damage to the wing's leading edge, aileron, and flaps. Engine debris came to rest on the only runway at the airport, causing the airport to be closed for several hours.

The National Transportation Safety Board's (NTSB) examination of the engine discovered an L-shaped crack in the outer pressure wall in the rear skirt area of the diffuser case that was deflected outward exposing the bulged combustion chamber inside the engine. The crack extended fore and aft approximately 18 inches from the diffuser case's rear flange at the 11 o'clock[1] position. The crack turned 90° and extended circumferentially around approximately 120° of the case's circumference, in the counterclockwise direction. The crack passed adjacent to a 3-inch long, dog bone-shaped embossment (boss), located about 10 inches forward of the rear flange at the 11 o'clock position. The boss was the attachment point for the upper most mount bracket of the engine's 116-pound precooler.[2]

[1] All references to the clock are as viewed from aft looking forward.

[2] The precooler is an air-to-air heat exchanger that cools the engine bleed air from the high-pressure compressor (HPC) with cooler fan discharge (ram) air. Pressurized air from the HPC is regulated by 8th- and 15th-stage bleed air valves before entering the precooler. Ram air is regulated by two valves as it exits the precooler.

A section of the diffuser case rear skirt (see figure 1) was examined at the Safety Board's materials laboratory in Washington, D.C. Examination of the fracture surface, approximately 10 ½ inches from the rear flange, adjacent to the upper precooler mount boss, revealed a 5-inch long discolored high cycle fatigue[3] (HCF) zone with about 90,000 striations. The fatigue initiated at a crack that looked like two thumbnail-shaped, gray-colored areas, which were approximately 0.040-inch wide by 0.010-inch deep. High levels of delta phase precipitate[4] were discovered in the thumbnail-shaped origin areas. Individual 0.0005 to 0.0008-inch deep toolmarks or scratches were found on the outer case wall extending the length of the origin area. Numerous additional toolmarks were found on the exterior surface of the rear skirt. The toolmarks were formed when the exterior surface of the case was machined (blended) during manufacture. The diffuser case had accumulated 9,342 total flight cycles[5] since new.

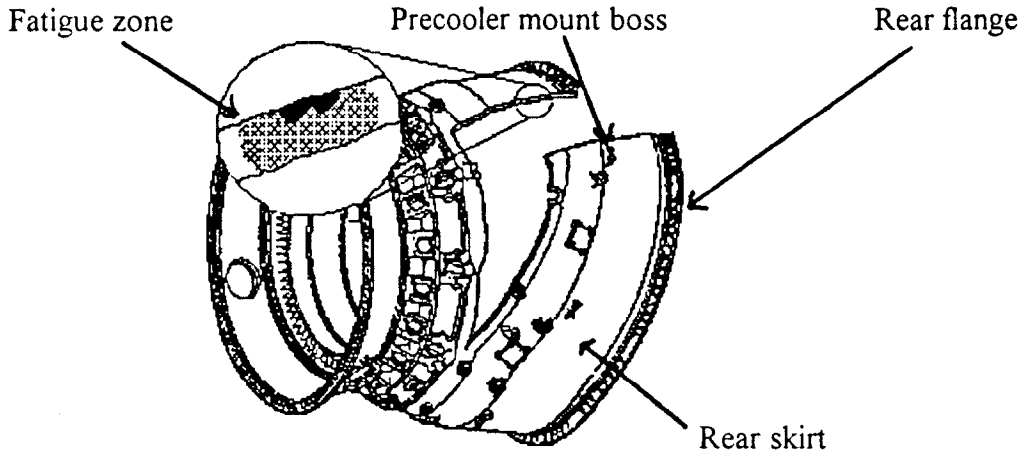

Figure 1: Ruptured diffuser case

A metallurgical analysis of the fracture surface indicated that the thumbnail-shaped cracks had initiated at the base of the toolmarks because of a combination of high residual stresses and low-cycle fatigue[6] (LCF). The crack then propagated in HCF, as evidenced by the very small striation spacing found in the majority of the 5-inch long fatigue zone, after which the crack progressed to failure in tensile overload.

Based on the morphology of the fracture, metallurgical tests were also conducted at P&W's Mechanics and Material Engineering laboratory, in East Hartford, Connecticut, to evaluate the case material's fatigue properties that were initiated by toolmarks. Specimens tested with toolmarks present were found to have one-fourth the predicted life of identical specimens tested without toolmarks.

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[3] HCF is a phenomenon in which a crack progresses an incremental amount (one striation) as a result of the cyclical stresses associated with vibration.

[4] The delta phase precipitate is a normally existing high temperature phase in INCONEL 718 and was most likely formed by the elevated temperatures associated with the heat treatment process of the diffuser case.

[5] A flight cycle is one takeoff and landing.

[6] LCF is a phenomenon in which a crack progresses an incremental amount (one striation) as a result of the cyclical stresses associated with rise and fall of the engine's internal pressure, temperature, or the revolutions per minute associated with each flight cycle.

Metallurgical examination of the precooler at the Safety Board's materials laboratory revealed HCF cracks at the attach points of two internal support rods. Seven other rods with identical HCF cracks were found to have been previously weld repaired. Wear marks and contact marks were also found on the engine bracket and support link of the precooler's upper attachment point. Additionally, a review of the maintenance records revealed that seven flight cycles before the diffuser case rupture, the engine had an in-flight shutdown (IFSD) because of a turbine cooling air (TCA) tube failure. The records revealed that during the inspection following the IFSD, the TCA tube mount clamp, which normally supports the tube at about mid-span, was discovered missing, and a station-4 static pressure sense line (Ps4) was also discovered to be fractured. The TCA tube and clamp, and the Ps4 line were replaced. The records also revealed that 260 flight cycles before the diffuser case rupture, a cracked lenticular seal[7] was discovered during disassembly of the high-pressure turbine.

The incident aircraft had no engine vibration monitoring (EVM) equipment. Although no EVM equipment was installed, the fractured diffuser case and Ps4 line, the missing TCA tube, the precooler cracks, and the precooler bracket wear suggest a vibratory environment. As a result, the Safety Board's investigation attempted to identify potentially vibratory resonant conditions or excitation sources within the engine. A vibration survey was performed at P&W on a normally operating JT9D-7R4 engine that had a similar diffuser case but no precooler. P&W also conducted finite element analyses of the JT9D-7Q's TCA tube installation and the precooler installation to determine the stresses from an assumed engine oscillatory force equivalent to 2.5 times the force of gravity, which is considered to be a high vibration level for this engine. Finally, P&W estimated the amount of vibratory excitation imparted to the engine because of a cracked lenticular seal.

The results of the vibration survey did not reveal any resonant conditions or excitation sources stemming from normal engine operation. The finite element analysis of the precooler installation revealed that the stresses from a high vibrating engine were not sufficient to initiate a crack in the case. Finally, the maximum levels of vibration from a cracked lenticular seal, or from a supported or unsupported resonating TCA tube, were not of sufficient magnitude to be excitation sources.

A review of the failure history of the JT9D-7Q since certification in 1978, revealed that this is the first diffuser case rupture originating in the rear skirt area. The JT9D-59A and -70, which have an interchangeable diffuser case with the JT9D-7Q, had two diffuser case rupture events early in their operation history; these originated in the front skirt area. Since the issuance of Airworthiness Directive 94-26-06, which requires inspection of the front skirt in the vicinity of the 15th-stage bleed air bosses, no additional ruptures have originated in the front skirt area.

The proximity of the crack origin to the precooler mount boss and the HCF crack propagation suggests that high precooler vibration imparted higher than normal loading into the precooler mount boss and the diffuser case. Additionally, the postincident fatigue tests of the case material indicates that high levels of vibration alone are insufficient to initiate a crack. The

[7] The lenticular seal is a torroid-shaped, steel seal clamped between the 1st-and 2nd-stage HPT disks that incorporates four knife edge seals around the outer diameter.

evidence also suggests that a tool mark or other defect in the case, combined with LCF, is required to initiate a crack and that high levels of vibration can propagate the crack.

As a result, P&W reports that it is drafting a service bulletin to propose a repair for toolmarks stemming from the blending of the diffuser case during manufacture. Additionally, Boeing reports that it is drafting a service letter that proposes a rework of the engine bracket to the precooler's upper attachment point on the JT9D-7Q installation to increase clearance between the bracket and support link to reduce vibration and to reduce wear.

Because it appears that preventative measures can obviate future diffuser case ruptures originating in the rear skirt area with minimal impact to airline operations, the Safety Board believes that the Federal Aviation Administration (FAA) should require a one-time visual inspection of the diffuser case rear skirt on P&W JT9D-7Q engines to locate scratches and tool marks when the diffuser case is next at the piece-part level, and blend repair as required to prevent tool marks and scratches from becoming crack initiation sites. The Safety Board also believes that the FAA should require modification of the engine bracket that attaches to the diffuser case's precooler upper mount boss on the P&W JT9D-7Q installation to increase clearance between the bracket and support link to reduce vibration and to reduce wear.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require a one-time visual inspection of the diffuser case rear skirt on Pratt & Whitney JT9D-7Q engines to locate scratches and tool marks when the diffuser case is next at the piece-part level, and blend repair as required to prevent tool marks and scratches from becoming crack initiation sites. (A-98-25)
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> Require modification of the engine bracket that attaches to the diffuser case's precooler upper mount boss on the Pratt & Whitney JT9D-7Q installation to increase clearance between the bracket and support link to reduce vibration and to reduce wear. (A-98-26)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman